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Countermobility Engineering Automation for Force XXI

by C. D. Butler, P. L. Doiron

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Prepared for Headquarters, U.S. Army Corps of Engineers

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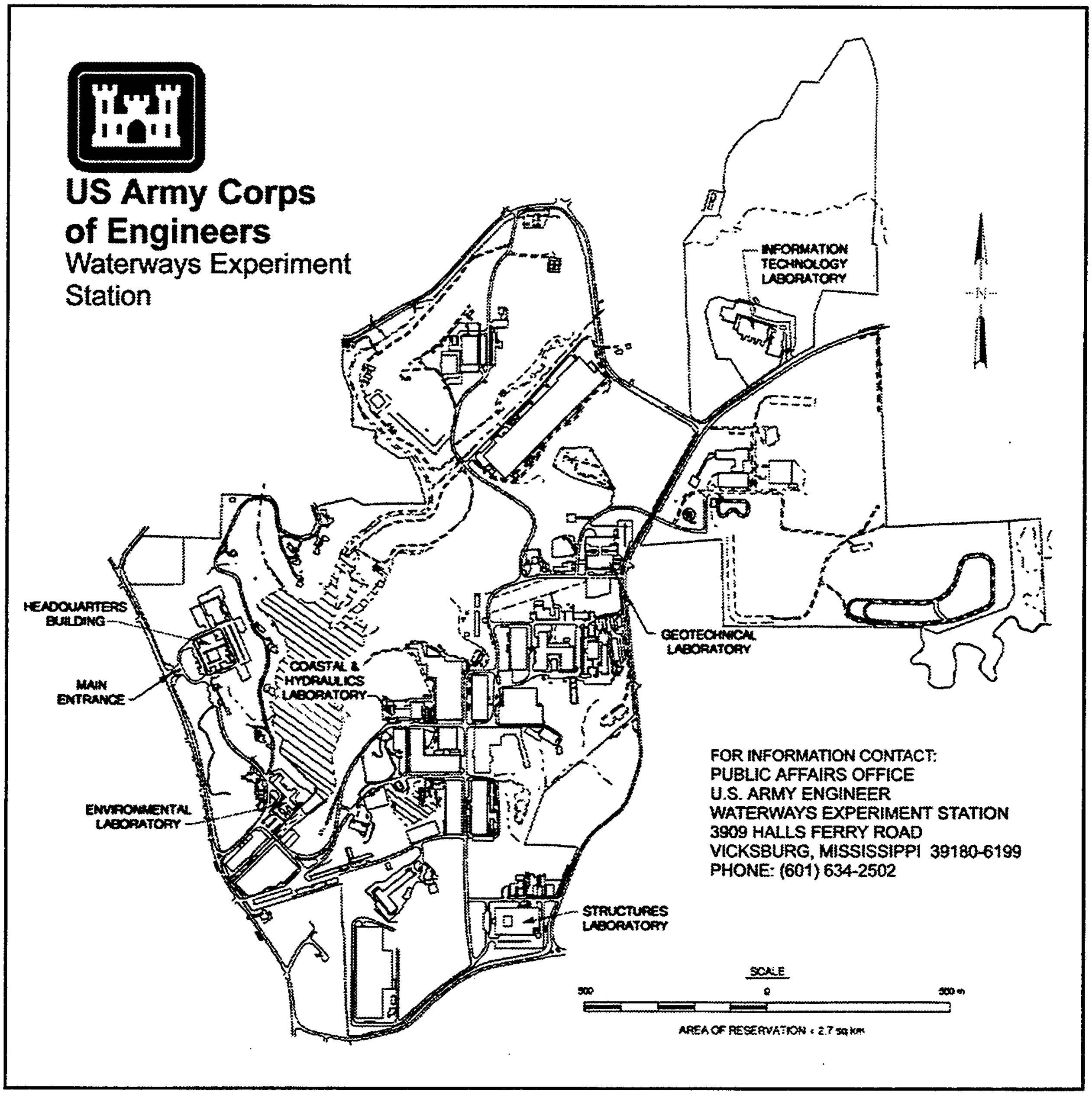

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Preface

This document reflects the efforts of the Mobility Systems Division (MSD), Geotechnical Laboratory (GL), U. S. Army Engineer Waterways Experiment Station (WES), in developing a state-of-the-art software capability for Countermobility Engineering Automation for Force XXI.

Funds for the development of the software capability described herein were provided through the Obstacle Planning Research, Development, Test, and Evaluation Work Package, Headquarters, U. S. Army Corps of Engineers (USACE), under Department of the Army Project No. 4A162719AT40, Work Units BP-009, Decision Algorithms for Obstacle Planning, and BP-012, Develop Synergistic Effects of Obstacles and Direct/Indirect Fire Weapons. Technical monitor was Mr. Mike Bonomolo, U. S. Army Engineer School.

This document describes the software and illustrates how it fits into the Force XXI concept.

This report was written by Messrs. Phillip. L. Doiron and Cary D. Butler, MSD. Ms. S. G. Sippel, MEVATEC Corporation, assisted with preparation of this report and figures.

All phases of this study were conducted under the direct supervision of Mr. Robert P. Smith, Chief, Modeling and Simulations Branch, MSD, and under the general supervision of Mr. Newell Murphy, Chief, MSD, and Dr. William F. Marcuson III, Chief, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

1 Introduction

With modern advances in the computing industry, the Army has committed to fielding an automated force by the turn of the century. The Army's vision of the future battlefield consists of groups of networked organizations organized around information and information technology that support the capability of reacting to dynamic situations. Today's Tactical Operations Center (TOC) will evolve into an information warehouse consisting of numerous command and control (C2) systems providing decision makers with the proper information at the precise time.

The Army's transformation into the 21st century will be organized around information technology. Future commanders will have the ability to access up-to-date information and apply this during their day-to-day operations. The fielding of such technologies will make information abundant and dynamic. This will undoubtedly create new challenges for future commanders and their staffs. If the goal is just in the distribution of information, the challenge becomes the staffs' ability to decipher the information that is critical and effectively apply this information in the decision process. In many cases, the tendency is to become overwhelmed with small details thus losing sight of the overall objectives of the plan.

As the Army proceeds with this vision, much can be learned from the business world. Over the past 30 years, businesses have spent billions of dollars in information technology. Studies have proven that automation does not guarantee an overall increase in effectiveness. In the past 20 years, blue-collar production has increased by approximately 15 to 20 percent. But during the same period, white-collar workers have procured billions of dollars of new hardware and software products and shown little or no increase in productivity. This can be attributed to computers increasing the complexity of use and understanding of the vast amounts of information rather than providing truly automated decision support capabilities.

Future C2 systems must go beyond the capabilities of today's information systems. These systems must incorporate Artificial Intelligence (AI)-based decision support tools necessary to allow these systems to become a part of the staff rather than just a tool used by the staff. This will enable the commanders and their staffs to generate, modify, and analyze complete, consistent, and robust plans and schedules in real-world, resource-constrained environments.

The U. S. Army Engineer Waterways Experiment Station (WES), in conjunction with the U. S. Army Engineer School (USAES), is conducting various research efforts in engineering automation. The Obstacle Planner Software (OPS) is one such effort focused on countermobility engineering. The results of the OPS research have been successfully applied in the Prairie Warrior 95 and 96 Advanced Warfighting Experiments, in Bosnia, Korea, and numerous exercises at Fort Hood. OPS provides an array of capabilities for combat engineering consisting of the following :

a. Mobility analysis

b. Mobility corridors

c. Task organization

d. Critical engineering resource tracking

e. Manual and automated obstacle emplacement procedures

f. Obstacle effectiveness

g. Engineering resource requirements

h. Class IV and V haul requirements

i. Engineering task scheduling

j. Syngeristic effects of direct and indirect fire weapons

k. Generation of obstacle reports

The greatest challenge in successfully developing OPS has been the seamless fit of these tools into the engineers' staff planning process. This paper aims to describe some of the most recent advances in countermobility research at WES in support of C2 capabilities being developed for combat engineering.

2 Force XXI Engineering

Combat engineers play a vital role in support of combat forces by performing missions in mobility, countermobility, survivability, and sustainment engineering. The planning and tracking of these engineering functions are the primary responsibility of combat engineers at corps, division, and brigade levels. Engineers today are faced with performing these tasks without the benefits of C2 automation. The manual process used today is augmented by a hybrid system consisting of commercially available PC-based software applications providing little more than a data repository.

Sorting through all the Force XXI literature, the description of battlefield automation becomes bewildering. The USAES describes engineer automation as a modernized and knowledge-based, digitized force capable of full and enhanced partnership with the Army's Force XXI. The mention of knowledge-based in this description identifies the requirement of incorporating techniques that contain intelligent-based applications that apply domain specific knowledge and inferencing abilities to solve complex problems not applicable to standard algorithmic-based solutions. A system meeting these requirements will greatly surpass the abilities of traditional information technology. Just having the ability to interrogate an abundance of information does not provide the engineer the level of automation needed to effectively participate on the future battlefield. Future engineering systems must have the capability to fully utilize the information in decision support, yet abstract the engineer from the abundance of information, therefore, allowing the information to become intellectually manageable. Engineer systems must employ domain specific knowledge and analytical-based models together in such a way that the system works synchronously with the engineer in solving complex engineering problems within the dynamics of Force XXI.

3 What is OPS?

Combat engineers are confronted with many of the same types of problems their nonmilitary counterparts solve daily with the aid of elaborate computer technology. However, combat engineers do not have access to computer-based technology to support their needs. The WES, working in conjunction with the USAES and U. S. Army Artificial Intelligence Center, have made significant strides in developing computer-based technologies that support combat engineering automation. The Obstacle Planner Research, Development, Test and Evaluation (RDT&E) Work Package which was developed in-house by WES includes priority research directed toward automating the engineer's countermobility process. At the conclusion of the research (FY97), OPS will be transitioned to the USAES as a prototype for the Tactical Engineer Command and Control System (TECCS). TECCS is the C2 system, targeted at Corps down to brigade levels that will support the engineers' participation in Force XXI.

OPS is the culmination of seven years of research in engineering automation. The uniqueness of OPS is founded on analytical-based engineering models that leverage the power of AI technologies to enhance the engineers' role on the digital battlefield. OPS assists the engineer through the four steps of obstacle planning:

a. Analyze the avenues of approach

b. Analyze battle positions for the defensive fight

c. Determine the obstacles required to enhance the kill zone

d. Allocate and schedule engineer resources to accomplish the required engineering tasks

OPS provides the combat engineer with automated assistance for rapid (real-time) and accurate assessment (analytical-based) in the above areas. Additionally, OPS provides analysis capabilities that allow the combat engineer to determine how effective the developed plan will be in support of the commander's guidance. The capabilities discussed above are all integrated into a user-friendly Graphical User Interface (GUI) package organized around the engineers' decision process.

4 Automated Obstacle Planning

Engineering planning is difficult due to the vast amounts of detail that must be managed and effectively applied. Currently, a top-down or divide-and-conquer approach is used which involves decomposing the original problem into several subproblems, each of which is easier to deal with. This process forces major issues to be resolved early during the planning process thus allowing engineers to focus on the problem at various levels of abstraction while minimizing the number of details which must be considered at any given time.

During this decomposition process, engineers at corps, division, and brigade levels are concerned with the resource requirements necessary to support the plan. Analytical-based models are applied that consider the types of equipment available, geographic features, and atmospheric conditions to determine the time and resources required to perform the task. This process replaces the existing technique of relying on planning factors documented in the field manuals.
As mentioned earlier, there are four basic steps in the obstacle planning scheme; however, incorporating the planning scheme into the decision process is where OPS provides major assistance to the engineer officer. Higher headquarters develop an Operation Plan, and this plan is then sent to lower headquarters to guide their actions in developing their own Operations Plan. There are six steps in this decision process: (a) receive orders from higher headquarters, (b) mission analysis, (c) course of action (COA) development, (d) COA analysis and comparison, (e) decision, and (f) submit orders to subordinate units. OPS supports the three main steps in this process - mission analysis, COA development, and COA analysis and comparison. The subsequent parts of this section will discuss three models (obstacle schema, COA feasibility, and COA analysis) developed in support of the engineers during the various steps of this process.

Obstacle Schema

During COA development, engineers at brigade and battalion levels are primarily responsible for the planning of obstacle belts and groups, respectively,

which are types of controlling measures used to provide guidance to subordinate units in developing an obstacle plan. During the planning process, engineers use a set of standard planning factors in determining the amount of resources (people and equipment) required to implement the obstacles. Using these estimates, engineers at the higher headquarters have the ability to lay out an obstacle plan using controlling obstacles and apply these estimates in preplanning the resourcing efforts necessary to implement the plan. In many cases, applying these factors grossly overestimates critical resource requirements and causes an inefficient distribution of critical engineering equipment, personnel, and class IV and V resources. The USAES challenged WES to develop an automated technique that provides the corps, division, and brigade engineers with a more robust capability in estimating engineering effort.

In OPS, each controlling obstacle (belt or group) is assigned an intent. These controlling measures are then passed down to engineers at the company levels who will determine the exact positions of the individual obstacles. Working at company level allows engineers to evaluate the controlling obstacle at such a level of detail that the actual positions of the individual obstacles can be determined. Detailed information like the enemy's mobility potential, the enemy's bridging assets, critical bridge locations, etc., would be rolled up into determining the best locations for the obstacle placement. This orderly development of individual obstacles into a combined effective effort is characterized as the obstacle schema.

The basis for the estimation of resources in the Field Manuals (FMs) is called engineer linear effort. This variable is based on the enemy's attack frontage multiplied by a constant based on the intent of the controlling minefield. The problem with using such a technique is that the results are the same regardless of the enemy capabilities, geographic characteristics, and atmospheric conditions. Relying on such a simplistic function for the purpose of planning can result in the rejection of a perfectly acceptable course of action.

The uniqueness of OPS is based on a set of analytical models used in determining key engineering information. The models are configured so that the output of one or many models can be the input into another. This building-block approach in constructing decision aids is the basis of computing the obstacle schema. The model's inputs are:

a. Enemy's cross country movement potential based on the NATO Reference Mobility Model (NRMM) (Ahlvin and Haley 1992) influenced by actual or historical weather conditions based on the Soil Moisture Strength Prediction model (SMSP).

b. Enemy's ability to ford, swim, or span drainage features in the area computed by the gap crossing models.

c. Enemy's tactical bridging ability (based on width associated with drainage features).

d. Position of friendly direct/indirect fire weapons based on force ratio model (Relative Combat Power (RCP)).

e. Transportation features (roads, bridges, etc.).

The five inputs identified above are used in constructing the problem space. Now, considering spatial dimensions and intent of the controlling obstacle, a search function can be applied which is driven based on locating the obstacle schema which minimizes engineer effort and supports the overall objective of the controlling obstacle.

An A* (Barr and Feigenbaum 1981) search algorithm used in the unit movement application provided an excellent starting point. However, this implementation was based on a single input, single goal problem. In the case of the obstacle schema, modifications were necessary to support multi-input and multi-goal problems. This problem was resolved by initially allowing the A* function to accept one or more input nodes and additionally allowing the calling function to control the search by providing its own successor, cost, and goal functions. Using this approach, A* task was minimized to just managing the search process.

The intent of the controlling obstacle is used in determining the input and goal nodes. Attributes associated with the obstacle provide information on the enemy's direction and the commander's intended direction of movement (N, NE, E, SE, S, SW, W, and NW) along with the intent (turn, block, fix, and disrupt) of the obstacle. Using this, a network can be derived consisting of input, intermediate, and goal nodes. The cost of moving from one node to the next is determined by the cost function based on the premise of what is bad for the enemy is good for the friendly.

The solution to the problem is an obstacle schema that meets the overall objective and minimizes the engineering effort required in constructing the obstacle. A* simply moves around in the problem space based on the direction of minimum cost (engineering effort). The A* continues searching until it has exhausted the entire search space or the caller's goal function reports the solution. Once an exit node is located, the overall linear effort and obstacle schema is determined by tracing backwards, starting with the goal node, through A*'s data structure.

The predicted linear effort generated by OPS can replace the FM's linear effort thereby providing higher headquarters' engineers with a much better estimation of resource requirements (Figure 1).

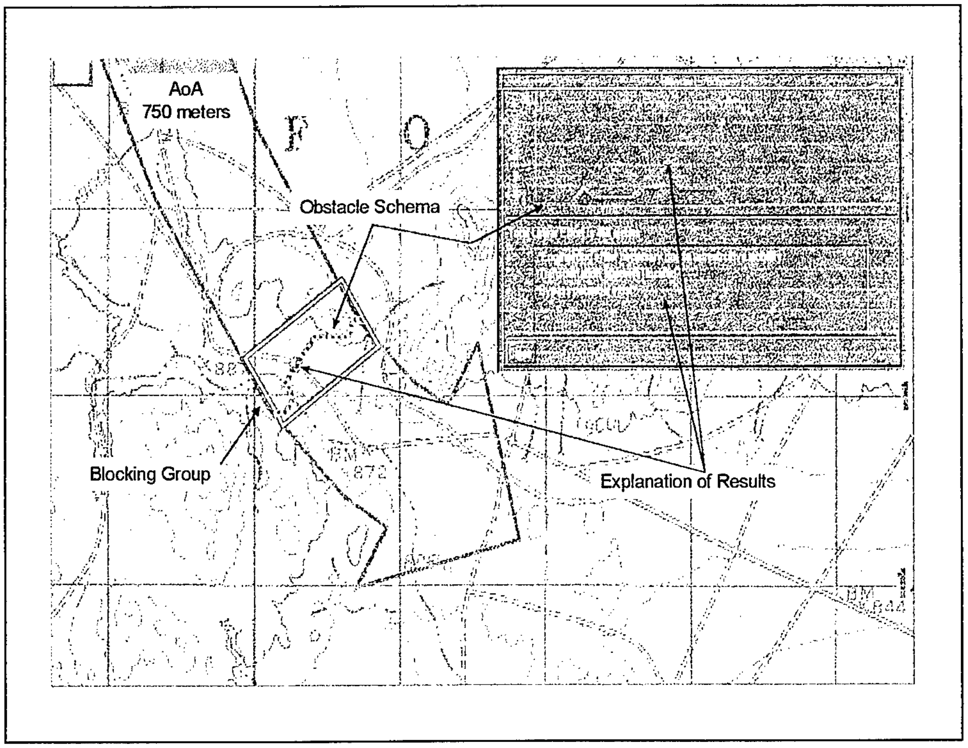

Figure 1. Determining Engineering Linear Effort

For example, consider the scenario in Figure 1 where an obstacle group is planned to block an avenue of approach (AoA) 750 m wide. In this case, the obstacle schema is perpendicular to the direction of the enemy. The X-axis on the insert in the upper right corner depicts a profile of the schema and the Y-axis represents engineering effort in squad hours. The user is allowed to move a vertical bar on the X-axis representing the schema. As the X-position changes, an icon is moved along the obstacle schema on the map illustrating the geographic position being described on the graph. Notice in this example little or no engineering efforts are required on the outer boundaries. The main engineering effort peaks on a transportation feature running through the obstacle group. At this point, the system is predicting efforts in dismantling the transportation feature along with mining the areas around the road to prevent the enemy from bypassing the damaged road.

As mentioned earlier, engineers at corps, division, and brigade level are concerned with supplying resources. Estimating resources at these levels is primarily accomplished through the use of a standard set of equations developed by the Engineer School. These equations allow engineers to preplan resource requirements early in the planning process. However, based on the scenario, they can sometimes overestimate the requirements. Estimation of requirements for the group in Figure 1 shows the doctrine-based process predicts a requirement of 60 engineer squad hours, with four blocking minefield packages requiring 72,000 lb of class IV and V materials transported to the location. Based on the obstacle schema model, the number drops to 30 engineer squad hours, with two blocking

packages only requiring 36,000 lb of class IV and V. Considering at any one time that engineers at corps or division could be supplying 30+ groups, differences of this magnitude could sway a commander from one COA to another.

COA Feasibility

Obstacle controlling measures are provided to subordinate units for further planning and refinement. Once the actual requirements are determined they are transmitted back up the echelon chain. Because the higher level engineers have access to the obstacle planning models, they can use this input for some initial resource planning. A common problem facing engineers at corps and division is subordinate units requisitioning more resources than essential resulting in an overall shortfall of engineering assets. Engineers responsible for supporting the requests must then assign priorities based on their understanding of the mission objectives and how the available resources can be best utilized in achieving the objectives. Engineers desire a capability that would allow them to collect all proposed tasks from subordinate units and determine the best configuration of engineering resources available based on the commander's guidance. This supplements the existing process of planning by adding capabilities that verify the request and assist in optimizing the distribution of the resources.

OPS supports this verification process by performing a depth-first (bottom up) search on the task organization tree in quest of maneuver units requiring engineering assistance. If such a condition is located, all supporting tasks are gathered, along with the engineers currently supporting the maneuver unit, and provided as input in the scheduling process. The scheduler predicts whether or not the maneuver unit has the capabilities required to perform the tasks identified within a given time. If the result is no, the unit icon on the task organization tree is shaded red; otherwise, the icon is shaded green. Engineers using this capability can see the shortfalls in the existing task organization, make the necessary modifications, and rerun the process until all maneuver units are green.

For example, Figure 2 provides a scenario that is based on two maneuver units requiring engineering assistance in support of a COA. During the COA development phase, engineering tasks were identified and associated with some maneuver unit based on the overall objectives of the mission. In the figure, maneuver battalion 1-12 is requesting 120 squad hours of engineering assistance while 2-8 is requiring 84 squad hours. Both maneuver units were previously assigned one engineering company each in support of their efforts. Constraints in the COA required all tasks to be performed in three days. The COA feasibility process predicts the 2-8 can meet the objectives of the commander; however, 1-12 was determined not to have sufficient engineering assets required to meet the objectives. This deficiency required the division engineer to provide an additional engineer company in direct support to the 1-12. Re-executing the feasibility process predicted the additional capability of the 957 Engineer Company will allow the 1-12 to complete all tasks within the timeline of the commander.

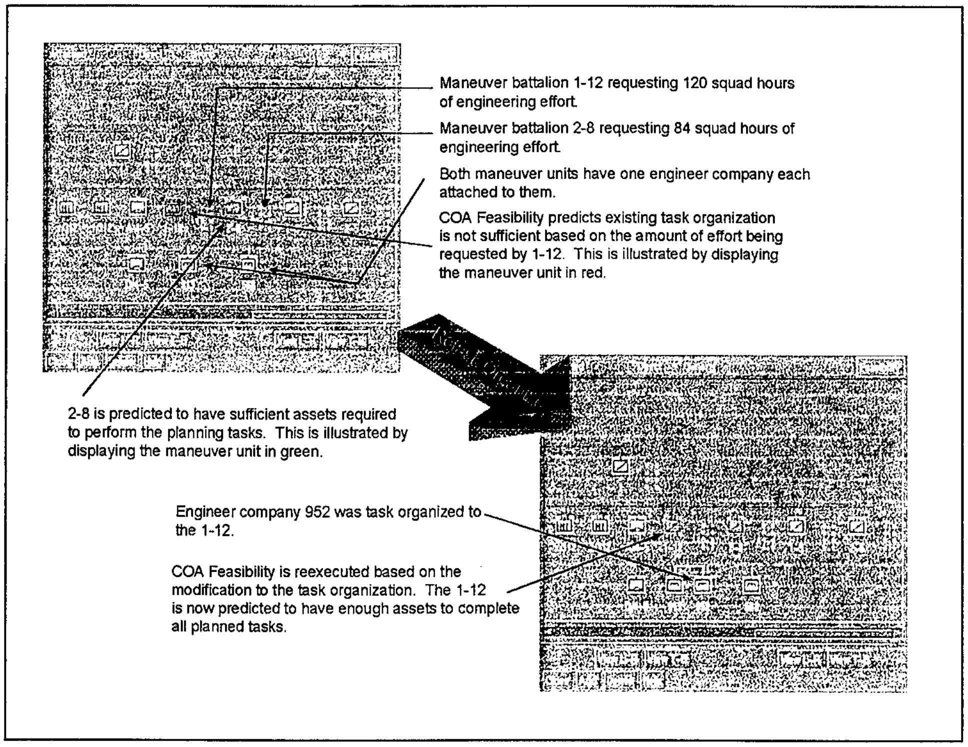

Figure 2. Retask Organize Based on COA Feasibility Results

Providing scheduling capabilities based on C2 hardware within the dynamics of the battlefield is a significant challenge. The complexity of this scheduling problem is 2(H*U*T) where H represents the time constraint in hrs required to complete all engineering tasks, U is the number of engineering units that are available to work on the tasks, and T represents the total number of engineering tasks required. An example scenario based on field gathered data shows a heavy maneuver brigade with nine organic engineering squads requesting 50+ engineering tasks to be performed over a three-day period. It is obvious that the problem space is beyond using standard numerical approaches. Additionally, consideration of movement times between tasks, resting periods (work hrs per day), and unit aggregation (more than one unit working on a single task at one given task slice) required the investigation into optional approaches. Because standard numerical techniques were considered as a means to generate the schedule but were rejected as being too time-consuming, other techniques were considered including simulated annealing, tabu search, and genetic algorithms. For the above-mentioned reasons, the genetic algorithms approach was chosen as the most promising technique for research and development of scheduling algorithms capable of evaluating engineering requirements versus engineering capabilities. This scheduling process, in conjunction with the task organization module, provides the tools necessary to assist in properly distributing engineers on the battlefield within the time constraints of the planning process.

COA Analysis

Engineers must have the ability to quickly analyze and prioritize each COA based on the engineers' ability to support the overall objectives of the commander. The engineer must first evaluate the feasibility of each COA; that is, whether the tasks can be performed within the time and asset constraints. Second, the engineer must determine whether the plans are effective; that is, to verify that each COA is properly integrated with the direct and/or indirect fires and capable of achieving the desired effects on the enemy's maneuver at the proper locations and times on the battlefield.

The feasibility of the plan, described in the previous section, is based on the availability of troops, equipment, materials, and time. In addition to COA feasibility, engineers must have the capability to evaluate overall effectiveness of engineering tasks in support of the commander's intent. This type of analysis requires knowledge of the current situation (unit positions, threat positions, unit effectiveness, etc.) and input from other staffs members (threat's AoAs, engagement areas, etc.) to predict the overall effectiveness of the engineers (Doiron et al. 1996). The remaining section will provide an in-depth view into the overall analysis process and how this works in conjunction with the process identified in ST-100-9 (U. S. Army Command and General Staff College 1992) and FM90-7 (U. S. Department of the Army 1994).

The COA analysis is modeled after the seven step war-gaming technique described in ST100-9. The steps are:

a. Gather the tools

b. List all friendly forces

c. List the assumptions delivered during mission analysis

d. List known critical events and decision points

e. Select a war game method

f. Select a technique to record and display the results

g. War game the battle and assess the results

The idea is to attempt to visualize the flow of the battlefield based on the effectiveness of units and their most likely actions and attempt to foresee the action, reaction, and counteraction dynamics of a battle (ST-100-9). Each of the seven steps and their subtasks are discussed in Table 1 and is based on information obtained from ST-100-9 and compared against the capabilities in OPS.

Table 1
Seven Steps in Course of Action Analysis as defined in ST100-9

Steps	Task	Action
Step 1	Gather the tools	This step involves acquiring maps of the area, posting the enemy template, and posting the current friendly unit disposition. Using OPS, the map background of the area being analyzed is available, the enemy template is obtained from the G2/S2 and entered into the software and displayed on the map background, and finally from the G3/S3 the current friendly unit disposition is obtained and entered into the software and displayed on the map background.
Step 2	List all friendly forces	This information is available from the Operations Plan for which the obstacle plan is developed to support. This listing of available forces and their assets are entered into the system and incorporated into the supporting database of units. The priority of support is dictated by the commander's intent obtained from the Operations Plan.
Step 3	List the assumptions during mission analysis	The assumptions listed during the mission analysis process are obtained from the Operations Plan. The engineer planner must take these assumptions into account when the obstacle plan is being developed.
Step 4	List known critical events and decision points	Known critical events and decision points are part of the commander's scheme of maneuver and as such are part of the Operations Plan. The engineer planner must address these events and points in the development of an obstacle plan to support the commander's intent.
Step 5	Select a war game method	There are three different war game methods that can be used for the analysis of a COA - Avenue-In-Depth technique, Belt technique, and Box technique. OPS uses the Avenue-In-Depth technique.
Step 6	Select a technique to record and display results	In this step, the user is to select either a narrative or sketch technique for recording the results of the COA analysis. OPS uses both of these techniques and supplies the engineer officer with a graphical representation of the analysis as well as a narrative description of the analysis results.
Step 7	War game the battle and assess the results	The methodology by which OPS performs the COA analysis and presents the results is detailed in the following paragraphs.

The unit movement algorithm is used in computing unit speeds and times along a predefined AoA. A unit is represented as a circle template that is overlaid on a grid consisting of speed values. The circle template is further subdivided into four parts (front, back, left, and right) to allow for the evaluation of the influence of terrain, direct/indirect fires, and man-made obstacles on the overall makeup of the unit. The movement rate of a unit is based on the combination of speed values located in the cells that comprise the circle at some point along the avenue. The underlying speeds used in predicting unit movement are based on the raster representation of the results of the NRMM which is one of the applications inherited by interfacing with the Terrain Evaluation Model (TEM). The NRMM-predicted speed is used in determining the movement rate of the unit based on the

tactical movement cost equations (Butler et al. 1996). Movement of the circle template along the avenue is performed by using a raster line drawing technique commonly known as Bresenham's line algorithm. The line algorithm finds series of cells that best represent a straight line between two end points. These cells are used in identifying the center of mass of a unit along the avenue. If the selected path contained way-points, this technique is repeated until all line segments are processed. Movement rates and times are determined by evaluating the speed of the circle template for each center of mass point along the avenue.

The other key component of the avenue-in-depth analysis is a rule-based module developed using C Language Integrated Product System (CLIPS). CLIPS is an expert system development package that provides the necessary tools for construction of rule based expert systems. CLIPS is based on a symbolic programming language unlike conventional programming languages such as C or FORTRAN; however, provisions are available which support interoperability between CLIPS and C. CLIPS allows knowledge to be represented as heuristics or "rules of thumb," which identifies an action to be performed for a given situation. The knowledge can then be manipulated and inferences drawn to solve problems considered too complex for standard algorithmic approaches.

Facts are the techniques used in representing information in CLIPS. A fact describes a single piece of information. At any time during the analysis, thousands of these facts can exist providing information necessary to activate predefined rules used in representing the knowledge. Rules are composed of an antecedent (if portion) and a consequent (then portion). Conditions of the rules are satisfied by existing facts that match the required condition of the antecedent. Activation of a rule causes the execution of the action identified in the consequent portion of the rule. The results of a rule activation can invoke additional rules. Rule activation continues until the system converges (no additional rules are applicable) on a solution. Models used in determining the effects of the obstacles, computing attrition, and deriving explanations are all based on the CLIPS paradigm.

As the unit movement module moves the center of the circle template one pixel along the defined AoA, the overlap between the four subdivisions of the circle template and the operational graphics along with the unit's current rate of movement, effectiveness, location, and time in travel are packaged into CLIPS fact structures and asserted into the rule-based module. These facts are used to inform the rule-based systems of events that are currently impacting the threat unit. At this point, rules that are sensitive to the input events are activated which could, in turn, activate additional rules. This process is repeated until no rules are queued for activation. Information associated with the unit's speed, effectiveness, and travel time are provided back to the unit movement module through the use of global variables (variables shared between the unit movement model and the CLIPS modules) accessed by the rule-based module. This step is continued until the center of mass of the circle template reaches the end point in the avenue.

In Figure 3, a threat battalion has moved along its AoA and has encountered an engagement area covered by a friendly battalion. The analysis of what will

happen is shown in the blue window which shows reduction in combat power with and without obstacles. Without obstacles, the threat unit will experience approximately a 40 percent reduction in combat power; with obstacles, the threat unit will be destroyed.

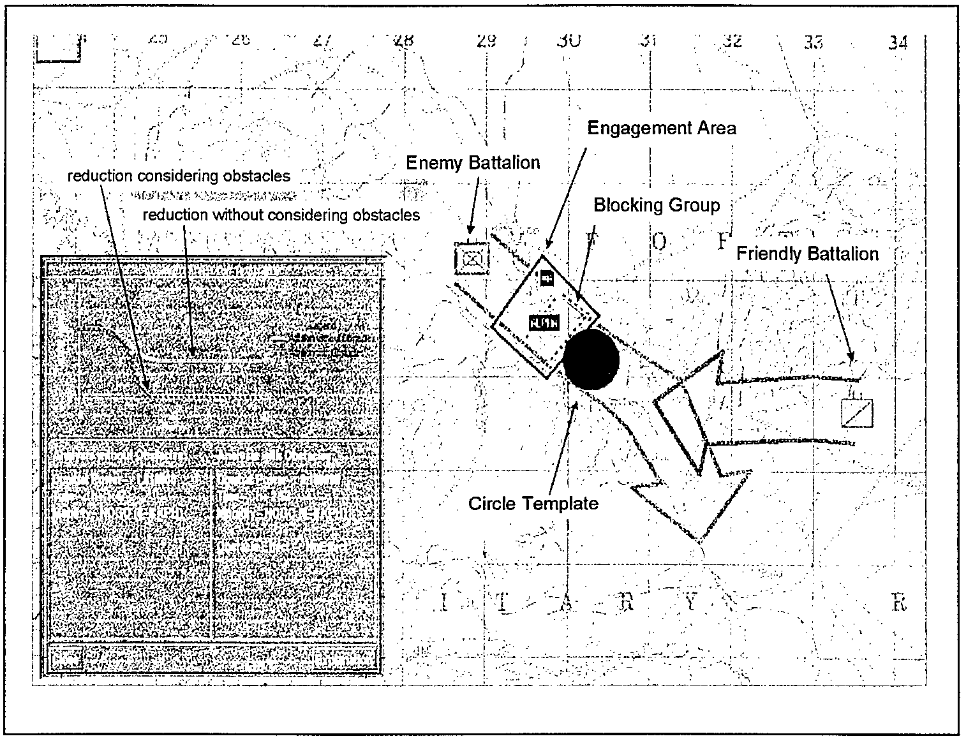

Figure 3. Results of the COA Analysis Process

In Figure 4, a threat battalion has moved along its AoA and has encountered an engagement area covered by a friendly battalion with close air support. The analysis of what could happen to this unit is shown in the lower blue window and the textual explanation generated by CLIPS is shown in the upper blue window. An extensive series of obstacles were planned to be used in the engagement area; however, the analysis, run two times, one without obstacles and one with obstacles, shows that with obstacles the threat battalion has an approximate 90 percent loss in combat power while moving through the engagement area and an approximate reduction of 90 percent without obstacles. This example illustrates the power of the analysis because it shows that the effort to emplace the obstacles in this engagement area would have little effect on the outcome of the battle, thus allowing these engineer assets to be used elsewhere on the battlefield.

After the analysis is completed, information resident in the knowledge-base is presented to an explanation component. The explanation component, developed using a generic-based mechanism for generating a spatial and temporal hypertext, describes key events of the analysis at various levels of details. Experts were used in identifying the type of explanations required. Their input was then used as the

basis for the explanation modeled using an augmented context-free grammar (CFG) which is commonly used in natural language processing and in the specification of programming languages. The CFG simplified the list of explanations into a very compact form. An example output from the explanation component is illustrated in Figure 4.

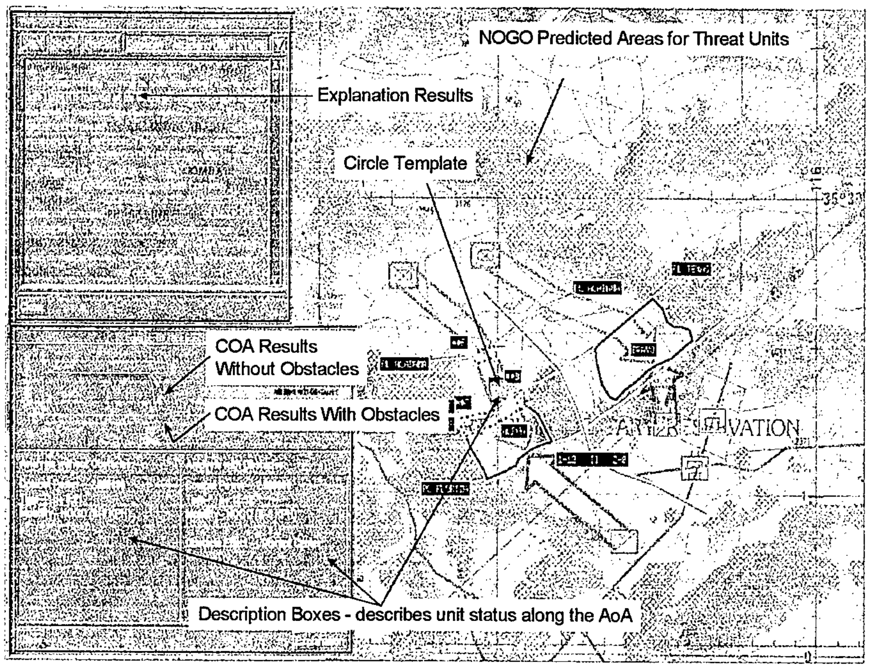

Figure 4. COA Analysis with Explanations

5 Real-World Usage

OPS was developed under the Corps of Engineers RDT&E program in a research environment. However, for OPS to be a functional software package, it was necessary to obtain feedback from the potential future users; the engineer officer in Army units. This feedback was necessary so that the software will reflect what the user needs and not what researchers say that they need.

In order to accomplish this goal, WES worked closely with active Army units and have attended numerous Command Post Exercises (CPXs) to develop user interface and functionality enhancements. These CPXs have been held at Fort Hood, Texas, Prairie Warrior 95 and 96 Advanced Warfighting Experiments at Fort Leavenworth, KS, and during the Ulchi Focus Lens 95 (UFL95) U. S./South Korean annual exercise. These exercises resulted in OPS being widely acclaimed to be one of the most useful decision making tools developed by the Army in the last decade.

III Corps

As OPS was being developed, WES established a relationship with the Corps Engineer Staff Section (CESS) at III Corps, Fort Hood, TX, to be evaluators of the software. Seven exercises were attended at Fort Hood working with the CESS for five of the exercises and with the Engineer Brigade of the 2nd Armored Division for two exercises. During these exercises, useful information was obtained allowing WES to develop a more robust and user-friendly software package that really helped the engineers. In fact, in the last exercise, WES placed a machine with the software in the Corps Engineer Operations Cell networked with another machine with the software in the Corps Engineer Planning Cell. During the exercise, information was received (i.e. unit status, engineer tasks, etc.) from the supporting engineer units, entered it into the software system, and analyses were performed based on this information. The CCES produced briefing slides and information for the engineers and sent this information to the PHOENIX machine in the G3 cell for inclusion in the commander(s) briefings. As the exercise progressed, it became apparent that the software was performing all of the required tasks in the Operations Cell. The updated engineer information was also sent to the Planning Cell for inclusion in

planning operations. The engineer planner's primary interest in using OPS was in tracking locations of enemy obstacles, division(s) obstacle belts, and performing planning for deep strike GATOR missions.

Prairie Warrior 95

During FY95, OPS Version 2.3 was turned over to the Demonstration Program at WES for inclusion in Prairie Warrior 95. The Demonstration Program was configured to take software developed in the Corps of Engineers research program and use it in a formal demonstration of its capabilities. The Prairie Warrior Advanced Warfighting Experiments held at Fort Leavenworth, KS, are used to evaluate new ways of planning and conducting combat operations using new doctrine and equipment. During the Prairie Warrior 95 exercise, OPS was renamed to TEM/OPS and was used in the Mobile Strike Force, the Data Fusion Center, and the Echelons-Above-Corps Planning Cell. There were three machines with the software networked together in the Mobile Strike Force; one in the Armor Brigade, one in the Light Brigade, and one in the Engineer Brigade. These machines were used by the engineer staff officers to plan engineer operations and to pass and receive information from the C2 system PHOENIX. Also, the machines were networked together so that engineer information was shared among all the engineer systems and locations. The TEM/OPS was selected as one of the top three systems at Prairie Warrior 95. The Prairie Warrior Combined Arms Assessment Team commented, "TEM-OPS clearly has great potential. It increases the effectiveness of the base systems in ABCS. TEM/OPS was used effectively with All Source Analysis System (ASAS), PHOENIX, AFATDS, and to enhance air defense and Combat Service Support (CSS) operations."

Ulchi Focus Lens 95 (UFL95)

As a direct result of the success of the software during Prairie Warrior 95, WES was requested by the engineer staff officer in the 101st Air Assault Division to attend the UFL95. The task was to use the software to support the planning and obstacle tracking operations required by the division engineer officer. The use of OPS was successful as it supported not only the engineer staff officer but other staff officers as well with different analyses. Participation in this exercise was important to the software development effort because for the first time the software supported a different type of maneuver division. At III Corps and Prairie Warrior, we were mainly involved with heavy units, but for UFL95 it supported a light unit. It was discovered that the software was able to produce many analyses in support of this unit but, more importantly, it was learned that the software needed to incorporate new analyses for this type of unit. Following UFL95, revisions were made and incorporated into the OPS.

Prairie Warrior 96

Following the very successful use of OPS (Version 3.0) in an exercise at Fort Hood, the software was turned over to the Demonstration Program for inclusion in Prairie Warrior 96. OPS, along with a suite of software on Survivability, was renamed TEM/E-OPS (Terrain Evaluation Module/Engineer - Operations). For Prairie Warrior 96, machines with the software were located in the Mobile Strike Force Mobility and Survivability Battlefield Operating System (BOS), the Division Support Command (DISCOM), the student corps (II Corps), and the TOC Bravo. During the exercise, the software was formally evaluated by contract personnel working for the USAES. This evaluation was used to formalize the usefulness and utility of the software to support the engineers. The evaluation was highly favorable with strong recommendations to the Engineer School to support and continue development of the software. The evaluation concluded that TEM/E-OPS is a valuable and effective tool for staff officers from brigade to corps.

Bosnia Support

In January 1996, OPS was taken to Europe to support Operation Joint Endeavor. Initially the machine was located at the Office of the Deputy Chief of Staff - Engineer (ODCSENG) in Heidelberg, Germany. However, once the required training for the operators was completed, the machine was moved to the U. S. Army, Europe (Forward) headquarters located in Hungary. Here the machine was used to perform analyses in support of the engineers and also to obtain detailed analyses from WES and present them for display via a split-based operations mode. Additionally, the machine provided the ability to display and plot-to-scale the minefields within the U. S. sector in Bosnia. This action has continued to the present. The only change was that the machine is now located in the Mine Fusion Center, Tuzla. Since the machine was moved to Tuzla, WES was constantly in touch with the Mine Fusion Center personnel and performed modifications to the software over the split-based network to display and plot the minefields desired. WES also developed software for the OPS that would allow the importing of an Excel spreadsheet containing the minefield information collected in Bosnia and to display and plot this information.

WES continue to be heavily involved in this effort as part of the Joint Countermine Task Force. WES' part in this effort is to develop, based on OPS, a database that will contain the minefield information presently in the spread sheet information along with scanned images of the minefield records given to the U. S. forces by the different factions in country and, if available, photos of the actual minefield site. OPS will be central repository of all of this information and will display the minefields. The displayed minefields will be transmitted to the Intelligence System for display and the Multispectral Image Scanning Processor for placement and printing of 1:25000 map sheets with the minefields on the map for universal use in the theater.

6 Conclusion

The completion of OPS is a major advancement in the area of automation for the combat engineer force. Methodologies developed in OPS can be expanded and/or modified to support other engineer analysis tools to produce an effective, state-of-the-art decision aid system. This system will help the engineers become integrated into the new Army based on Force XXI doctrine.

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13. ABSTRACT *(Maximum 200 words)*

The Army's vision of the future battlefield consists of groups of networked organizations organized around information and information technology that support the capability of reacting to dynamic situations. Today's Tactical Operations Center will evolve into an information warehouse consisting of numerous command and control (C2) systems providing decision makers with the proper information at the precise time. Future commanders will have the ability to access up-to-date information and apply this during their day-to-day operations.

Future C2 systems must go beyond the capabilities of today's information systems. These systems must incorporate Artificial Intelligence-based decision support tools necessary to allow these systems to become a part of the staff rather than just a tool used by the staff. This will enable the commanders and their staffs to generate, modify, and analyze complete, consistent, and robust plans and schedules in real-world, resource-constrained environments.

The U.S. Army Engineer Waterways Experiment Station is conducting various research efforts in conjunction with the U.S. Army Engineer School in engineering automation. The Obstacle Planner Software is one such effort focused on countermobility modeling.

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